A LABORATORY STUDY OF WARM MIX ASPHALT FOR MOISTURE DAMAGE POTENTIAL AND PERFORMANCES ISSUES

By

SUSHANTA BHUSAL

Bachelor of Science in Civil Engineering

Institute of Engineering

Kathmandu, Nepal

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A LABORATORY STUDY OF WARM MIX

ASPHALT FOR MOISTURE DAMAGE POTENTIAL

AND PERFORMANCES ISSUES

Thesis Approved:

Dr. Stephen A Cross

Thesis Adviser

Dr. William F. McTernan

Committee Member

Dr. Rifat Bulut

Committee Member

Dr. Hyung Seok (David) Jeong

Committee Member

Dr. A. Gordon Emslie

Dean of the Graduate College

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INTRODUCTION

Thousands of miles of roads are constructed and maintained each year in the United States using conventional asphalt paving technology. Rapid global warming and the fuel energy crisis have made engineers rethink the use of conventional hot mix asphalt (HMA) technology. The cost of heating aggregates and asphalt during mixing and compaction has increased due to increased energy costs and also results in production of greenhouse gases. Increased environmental awareness has resulted in establishment of limiting criteria for emissions of green house gases, as evidenced by the Kyoto protocol.

Recent developments in asphalt paving technology have resulted in new ways to construct asphalt pavement by decreasing the mixing and compaction temperatures. Cold mix asphalt has been used as an alternative to HMA, reducing mixing and compaction temperatures by the use of asphalt emulsions [1]. This has been beneficial in reducing mixing and compaction temperatures and fuel consumption, but lack of proper aggregate coating, higher air void contents, less mix workability and reduction of strength for long term performance has made it unsuitable for all conditions [1]. To overcome the shortcoming of cold mix asphalt a new technology, warm mix asphalt (WMA), has been introduced which works between cold and hot mix asphalt temperatures [2].

WMA refers to the mixing and compaction of the aggregates and asphalt at temperature lower than conventional hot mix asphalt by the addition of additives. Traditional hot mixtures are mixed and compacted above 300 ˚F whereas WMA is mixed and compacted at 50 ˚ F lower than HMA with no compromise in quality or performance [2]. This reduction in temperature means less fuel required for heating which will decrease energy costs in production. Also, the decrease in fuel consumption will lessen greenhouse gas emissions, making it more environmental friendly. WMA has also been reported to make it easier for paving in colder climates, turning pavement over quickly for traffic which results in less cracking as the binder will not age as much during construction [2].

The history of WMA technology goes back to late 1990's.It was originally developed and implemented in Europe. Today, it is popular in the United States and around the world. The capability of the reducing the temperature and making it more efficient and workable without a decrease in quality has been the key factor in the increased interest in WMA. Warm mix asphalt construction follows existing HMA standards and procedures [2]. Superpave methods are used for mixing and compaction of WMA mixtures. The additives are added while mixing, decreasing the viscosity of the binder resulting in good workability and proper aggregate binder coating at reduced mixing temperature [2].

There are several types of additives used for constructing WMA [2, 3 and 4]:

1. Aspha-min®, a Eurovia Service GmbH product from Germany.
2. Sasobit®, a product of Sasol from South Africa.

3. Evotherm®, a product from MeadWestvaco Asphalt Innovations, Charleston, South Carolina.
4. Asphaltan B®, a Romonta GmbH product from Germany.
5. Doubel Barrel® Green, product from Astec Industries Inc. USA
6. Low Energy Asphalt, a product from McConnaughay Technologies, USA
7. Rediset™ WMX, Azko Nobel Surfactants, USA
8. Revix™, a product from Mathy Technology and Engineering Services, Inc. USA
9. WAM Foam, United States BP Bitumen

All of these additives have been used to reduce the viscosity of the binder and allow proper mixing and compaction of the asphalt mixture at warm temperature. Figure1 shows the working temperature of warm mix asphalt compared to HMA and cold mix asphalt [5].

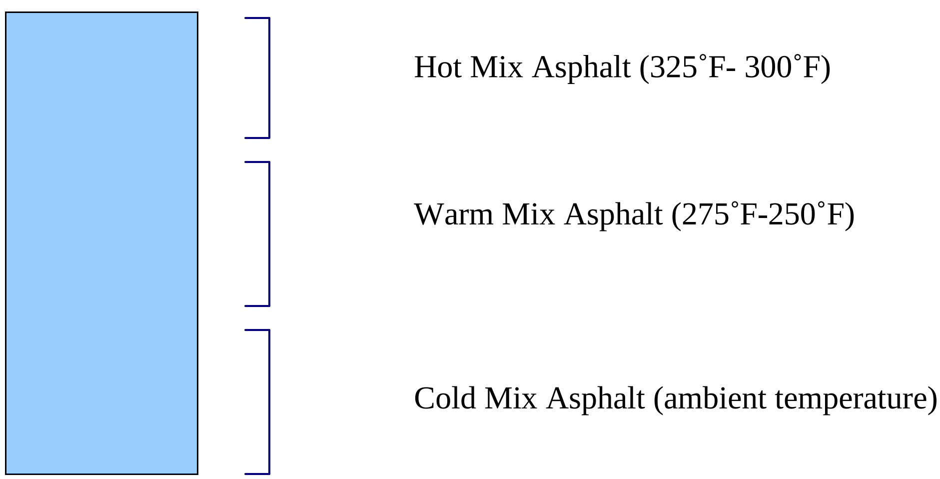

Figure 1 Working Temperature of WMA

PROBLEM STATEMENT

WMA is a relatively new technology that holds great promise for advancing paving technology in the United States. Laboratory and field data on performance of WMA with respect to applications in the Unites States are limited. One of the major concerns with WMA comes from its production at lower temperatures, therefore, complete drying of the aggregates may not be achieved. This could result in increased potential for moisture damage and reduced pavement performance due to moisture induced damages. Moisture-induced damage can lead the pavement to severe distressed like stripping, localized bleeding, potholes, shoving and structural failure due to moisture intrusion in asphalt pavements. Also the stiffness and compactibility of WMA needs to be addressed.

OBJECTIVE

The objective of this research was to determine the applicability of WMA additives with respect to environmental and operational paving condition found in North America. A laboratory study was performed to evaluate the moisture damage potential, rutting potential, mixture stiffness and densification of asphalt mixtures made with two WMA additives compared to the same mix made using conventional methods.

RESEARCH APPROACH

A laboratory study was performed to: (a) evaluate the moisture damage potential of WMA; (b) evaluate the dynamic modulus of WMA; and (c) evaluate the effect of mix temperatures on densification of WMA. Two WMA additives, Aspha-min and Sasobit, and an anti-stripping agent were used for the study. A PG 64-22 asphalt binder and granite aggregates were used to make WMA and control mixes. Test samples were prepared with and without WMA additives. The test results were analyzed and the performance of WMA was evaluated and compared to conventional HMA.

CHAPTER II

REVIEW OF LITERATURE

Warm mix asphalt technology is a new development in road paving technology that is gaining increased popularity in recent years. Decrease in production cost and fewer emissions of green house gases are the main factors behind its increased popularity in paving industry. WMA technology was first developed in Europe during 1990's. It was introduced in the United States in 2002, after the National Asphalt Pavement Association (NAPA) WMA study tour to Europe [6]. Report from European scan tour has stated several advantages of WMA technology as reduced fuel usage and emission, improved field compaction in cold weather paving and better working conditions [6].

WMA ADDITIVES

Aspha-min®

Aspha-min is a product of Eurovia Service Gmbh, based in Bottrop, Germany. It is available in very fine white powder form in 25 or 50 kg bags. It is a manufactured synthetic zeolite (sodium aluminum silicate), which has been hydro thermally crystallized [3]. Zeolites are framework silicates with empty space, this allows space for large cations such as sodium, calcium, potassium and water molecules.

Ability of losing and absorbing the water without damaging the crystal structure characterizes Aspha-min [7]. Aspha-min contains approximately 21 % water by mass [3]. By adding Aspha-min to the mix at the same time binder is added, water is released with the formation of fine water vapor which then expands the volume of the binder resulting in the formation of asphalt foam. This foaming allows the mix to have good workability and aggregate coating at lower mixing temperatures [7]. The temperature range of adding Aspha-min is 185˚F-360˚ F [2]. Eurovia suggests the addition of Aspha-min at 0.3% by weight of total mix will result in a 54˚ F (30˚C) reduction in typical HMA production temperatures [7]. Figure 2 shows the powder form of Zeolite.

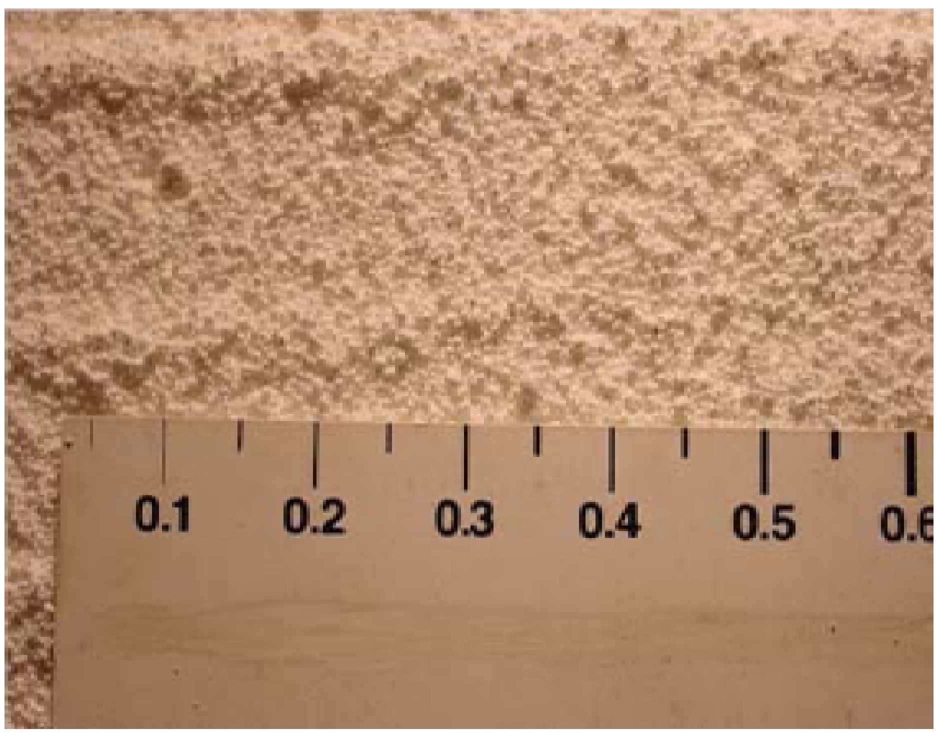

Figure 2 Powder form of Zeolite [8]

Sasobit

Sasobit® is a product of Sasol Wax of South Africa. It is a long chain aliphatic polymethylene hydrocarbon produced from coal or natural gas by gasification using Fisher- Tropsch (FT) process [3]. It has a fine crystalline form and is available in 5, 20 and 500 kg bags. Sasobit obtained from the FT process contains long chain lengths of hydrocarbons ranging from 14 to 115 carbon atoms [3]. Sasobit is described as “asphalt flow improver” due to its ability to decrease the viscosity of binder at lower mix production temperatures [7]. This decrease in binder viscosity reduces the mixing and compaction temperatures by 30-98˚F [7]. Sasobit is added at 0.8-4 % by weight of binder, as recommended by Sasol Wax [3].The melting point of sasobit is 216˚F and it is completely soluble in asphalt binder at temperatures higher than 248 ˚F [7]. Figure 3 shows the crystalline form of Sasobit.

Figure 3 Crystal structure of Sasobit [9]

PERFORMANCES STUDIES

According to the report from the 2002 European Scan Tour [6], the field performance of WMA pavement was found to be the same as conventional HMA pavements. In US the oldest WMA pavement was constructed in 2004 at Highway 115 Charlotte, NC. The pavement was found in excellent condition after 2 years [2].

Daniel [10] conducted a field and laboratory study on the entrance road to Hookset Crushed Stone to evaluate the moisture sensitivity of WMA. Two WMA additives, Sasobit and Aspha-min, were used. The tensile strength ratio (TSR) test results showed that WMA was more moisture sensitive than conventional HMA.

The National Center for Asphalt Technology (NCAT) [11, 12] conducted a laboratory study to determine the applicability of two WMA additives, Sasobit and Aspha-min, for typical paving operation and environmental conditions. Two aggregate types, limestone and granite, were used. A Superpave gyratory compactor (SGC) and Asphalt vibratory compactor (AVC) were used to evaluate the mixes ability to compact over a range of temperatures. The compaction temperatures for the mixes were 300˚F, 264˚F, 230˚F, and 190˚F, with the mixing temperature about 35 ˚F above the compaction temperature. Resilient modulus tests were performed to measure the stiffness of the mix. An asphalt Pavement Analyzer (APA) was used to determine the rut resistance of mixes. Hamburg Wheel Tracking tests and TSR tests were performed to determine the moisture sensitivity of the WMA mixes.

Densification test results showed that both WMA additives, Sasobit and Aspha-min, improved the compactability of the mixture by lowering the air void level in both SGC and AVC compaction. Resilient modulus test results showed that the addition of WMA additives did not have a significant effect on resilient modulus. APA test results also showed that the addition of WMA additives did not increase the rutting potential of the mixes. Hamburg wheel tracking test and TSR test results showed that WMA mixes increased the potential for moisture damage at lower compaction temperatures. The addition of an anti-stripping agent and hydrated lime increased the moisture resistance of WMA mixes compacted at lower temperatures.

Michigan Technological University [5] conducted a study on laboratory evaluation and pavement design for WMA using Aspha-min and PG 64-28 binder. Dynamic modulus tests (E*) were performed to evaluate the performance of WMA made of Ashpa-min. The test results and analysis showed that WMA with Ashpa-min did not have a significant effect in the Dynamic modulus (E*). It was also found that increasing amount of Ashpa-min improved the rutting resistance of the mixture significantly.

The Virginia Transportation Research Council [13] reviewed the installation of several WMA projects in Virginia. Three trial sections were installed using WMA technologies. Sasobit was used for two sections and Evotherm was used for the third section. Loose mix samples of conventional HMA and WMA were collected at the hot mix plant to perform Superpave volumetrics tests. Field core sample were taken from the trial sections to perform moisture sensitivity TSR tests using AASTHO T 283, rutting susceptibility tests using the APA and permeability tests using a flexible wall permeameter. Asphalt fume sampling was also conducted at the Evotherm installation to evaluate the differences in worker exposure between HMA and WMA pavement lay down operations.

It was found that WMA can be successfully implemented using conventional HMA paving practices with minor modifications to account for temperature reductions. The test results and analysis showed that no significant differences in volumetric properties were found for WMA compared to HMA. For Sasobit, the TSR test results showed inconsistent results. For one trial section, results showed higher WMA TSR's than control values and the other trial section showed lower WMA TSR's than control values. Both sections failed to meet the specification requirements for TSR. For Evotherm, the WMA TSR's test results were lower than control values and also failed to meet specification requirements. The APA test results showed that for Sasobit, there was no significant difference in rutting resistance compare to control, whereas, Evotherm exceeded the maximum allowable rutting depths. Permeability test results were similar for both WMA and control. Asphalt fume sampling conducted at the Evotherm installation showed that crew members were exposed to below the maximum recommended exposure levels of airborne asphalt fumes.

The University of Washington [14] conducted a study on WMA for cold weather paving. A literature reviews and surveys were conducted among the Iceland paving industry professionals about the three WMA additives; WAM Foam, Ashpa-min and Sasobit. Based on the surveys and interviews, it was found that WMA was a viable option for cold weather paving conditions in Iceland. For the three WMA additives Sasobit was reported as the most suitable.

A comparative laboratory study was conducted by the University of Oklahoma [15] to evaluate the rheological properties of PG 64-22 and PG 70-28 binder with and without WMA additives and the rutting potential of WMA mixtures. Rotational viscometer and and dynamic shear rheometer tests were performed to evaluate rheological properties of the binders. For rutting potential, APA testing was performed. Rotational viscometer test results showed that Sasobit significantly reduced the mixing temperature of PG 64-22 by 16˚C and PG 70-28 by 12˚C. For Aspha-min, no significant decrease in mixing temperature was found using the rotational viscometer. Test results from the dynamic shear rheometer testing showed no negative effect on high temperature binder grading due to high temperature viscosity reduction. Results showed Sasobit increased the high temperature binder grading of PG 64 and PG 70 to PG 69 and PG 75, respectively. No significant change in binder grading were found using Aspha-min. Test results from APA rutting test showed a significant reduction in rut depths using Sasobit whereas smaller reductions were found using Aspha-min.

CHAPTER III

TEST PLAN

OBJECTIVE

The objective of this research was to determine the applicability of WMA additives with respect to environmental and operational paving condition. A laboratory study was performed to evaluate the moisture damage potential, rutting potential, mixture stiffness and densification of asphalt mixtures made with two WMA additives compared to the same mix made using conventional methods.

MATERIALS

Asphalt

The asphalt cement used in this study was a PG 64-22 from Valero. The specific gravity was reported as 1.025.

Aggregate

To meet the objectives a mix that was prone to stirpping and had moderate stability (rutting resistance) was desired. The aggregate used in this study was granite obtained from Martin-Marietta's Snyder quarry west of Lawton, Oklahoma.

The ODOT pit number for the source aggregate is 3802.The aggregate source properties and ODOT requirements are shown in Table 1 [16].

Table 1 Source Properties of Aggregate

Property	**Test Method**	**Results**	**ODOT Specification**
L. A Abrasion	AASTHO T 96	20%	40 % max.
Durability Index	AASTHO T 210	81%	40 % min.
Insoluble Residue	ODD L 25	99.4%	40 %min
Micro-Devel	AASTHO T 327	5.5%	25.5 % max.

Three different stockpiles of aggregate were sampled to make the design mix, 5/8” chips, C-33 sand and screenings. Table 2 shows the gradation of each material.

Table 2 Combined Source Aggregate Gradation

Sieve Size	**5/8" Chips % Passing**	**C-33 Screening % Passing**	**Screening % Passing**
3/4"	100	100	100
1/2"	89	100	100
3/8"	55	100	100
No. 4	12	98	97
No. 8	3	72	73
No. 16		43	52
No. 30		24	36
No. 50		10	25
No. 100		3	16
No. 200		1	10

WMA Additives

Two WMA additives were evaluated for the research, a Zeolite, called Aspha-min and a Sasol wax, called Sasobit.

Aspha-min is a product of Eurovia Service Gmbh based in Bottrop, Germany. It was added to the mix at 0.3% by total weight of the mix. The dosage rate of Zeolite was based on binder rheology testing provided by University of Oklahoma. This was also the typical dosage rate for Zeolite (0.25%-0.3%) reported in the literature [3].

The second WMA additive used in the research was Sasobit, a Sasol Wax of South Africa. It was added at 1.5% to asphalt cement, based on the weight of the binder. The dosage rate was based on the binder rheology testing provided by University of Oklahoma. This was also the typical dosage rate for Sasobit (0.8%- 4%) reported in literature [3].

Anti- Strip Agent

An anti –stripping agent (ANS) was required for the Control mix to meet the minimum tensile strength ration (TSR) specification requirement. The anti-strip was from Azko –Nobel, trade name Perma Tac Plus. It was added 0.5 % to asphalt cement, based on the weight of binder. This is the rate recommended by ODOT.

MIX DESIGN

An ODOT S- 4 mix was selected for the study. To make the aggregate structure for the S-4 mix, each aggregate (5/8 chips, C-33 sand & screenings) was separated by size through the number 50 sieve. The individual sizes were then recombined to meet the gradation requirement of an ODOT S-4 mix. Table 3 shows the design S-4 gradation of the aggregate used in the study.

To determine the mix design for the research project, AASTHO M-323-04 “Superpave Volumetric Mix Design” was followed. Several trials were evaluated in order to find a design aggregate structure that met the S-4 mix requirements and blend 9 was selected as the design blend. Table 3 and 4 show the design aggregate gradation and volumetric properties of the design mix blend, respectively.

Table 3 Design Gradation of S-4 Mix

Sieve size	% passing	ODOT S-4 Gradation limit
3/4	100	100
1/2	95	90-100
3/8	85	
No 4	60	
No 8	44	34-58
No 16	32	
No 30	23	
No 50	12	
No 100	8	
No 200	5	10-2

Table 4 Design Blend 9 Average Volumetric Properties

ODOT S-4 Mix		ODOT Specification
Ndes	100	3<30 million ESALs
AC(%)	5.3	4.6% min
%Gmm @ Nini	87.7%	N/A
Gmb	2.332	N/A
Gmm	2.430	N/A
Gsb	2.579	N/A
VTM(%)	4.0 %	4.0 %
VMA(%)	14.4 %	14 % min
VFA(%)	72.0 %	(69-74)%

N/A= Not Applicable

The consensus properties of the blended aggregate were also determined. They are shown in Table 5.

Table 5 Consensus Properties of Source Aggregates

Properties	**Results**	**Test Method**	**ODOT Specification**
Gsb	2.579	AASTHO T 84& T 85	N/A
Fracture Face	100%	OHD L- 18	85 % min
FAA	46.4%	AASTHO T304	45 % min
Sand Equivalent	80	AASTHO T 176	45 % min.

N/A= Not Applicable

SAMPLE PREPARATION

All test samples were made to the job mix formula at optimum asphalt content (AC) from the mix design previously described. Samples prepared with and without WMA additives (Aspha-min & Sasobit) were termed as WMA and Control samples, respectively. The Control samples were prepared by mixing heated aggregate and asphalt cement in a bucket mixer at 325 ˚ F, followed by curing in an oven at 300˚ F for two hours, and then compacting at 300˚ F. The WMA samples were prepared using two different additives Aspha-min and Sasobit. The heated aggregate, asphalt cement and additives were mixed in the bucket mixer, followed by curing for two hours and compacted over a range of temperatures. Table 6 shows the WMA temperatures for mixing, curing and compaction of WMA samples.

Table 6 Mixing Temperatures for WMA Mixes

Mixing Temp (˚ F)	Curing Temp (˚ F)	Compaction Temp (˚ F)
325	300	300
275	250	250
250	225	225
225	200	200

The temperature of the asphalt cement during mixing was held constant at 325 ˚ F for all samples. Aspha-min was added to the heated aggregate using two different methods referred to as methods (a) and (b). In method (a) Aspha-min was added to the heated aggregate inside the bucket mixer and mixed with the aggregate by stirring with a spoon, similar to adding hydrated lime. Asphalt cement was then added and the whole mix (aggregate, Aspha-min and asphalt cement) was mixed in the bucket mixer. In method (b), a crater was created in the heated aggregate in the bucket mixer. Aspha-min was added to the crater, asphalt cement was then added on top of the additive and the whole mix (aggregate, Aspha-min and asphalt cement) was mixed in the bucket mixer.

The second additive, Sasobit, is a wax that is dissolved into the hot asphalt cement prior to mixing. It was added to the heated asphalt cement binder 15-20 minutes prior to mixing and was stirred often to completely dissolve it in the asphalt binder. The solution of Sasobit and asphalt cement was then poured on top of the heated aggregate inside the bucket mixer and mixed.

For Control and WMA samples with Anti-strip agent, the liquid anti-strip was added to the heated asphalt cement binder 15 minutes prior to mixing and stirred to completely disperse the liquid. The binder solution of asphalt cement and Anti-strip was then poured over the heated aggregate inside bucket and mixed.

TEST PLAN

The objective was to evaluate the WMA additives with respect to moisture damage potential, moisture induced rutting potential, dynamic modulus and compactibility of the asphalt paving mixtures.

To meet the objectives of this study the following tests were performed:

1. Moisture sensitivity (ASTM D 4867)

2. Hamburg wheel rutting test (Tex -242-F), (AASTHO T 324-04)

3 .Dynamics modulus test (E*) (AASTHO TP 62)

4. Densification

   (a) Superpave Gyratory Compaction (SGC)

   (b) Asphalt Vibratory Compaction (AVC)

MOISTURE SENSITIVITY TEST

ASTM D 4867 was followed to perform the moisture sensitivity test. The test evaluates moisture induced damage of compacted asphalt mixtures by measuring the tensile strength ratio of control and saturated (conditioned) samples.

Test samples were made to the JMF at optimum AC from the mix design previously described. A total of six sets of samples were prepared. Each set contained six samples. Two sets of control samples were made with and without Anti-strip. The other four sets were WMA samples containing Aspha-min and Sasobit, each with and without Anti-strip, respectively. For mix samples containing Aspha-min, mixing method (a) was used. The compaction temperature for all WMA samples was 300˚ F. The samples were compacted in a Superpave Gyratory Compactor(SGC) to the specified height of 95 mm and 150 mm diameter to 7 %(±0.5) air voids. The samples were then divided into two subsets so that the average air voids were approximately equal. One subset of samples was used for control or dry specimens and other for conditioned. The optional freeze cycle was used for conditioned specimens. The testing of control and conditioned specimen were carried out 77 (±1) ˚ F. The maximum compressive strength was noted on the testing machine and the indirect tensile strength was calculated. Specimens were pulled apart at the crack and visually inspected for moisture damage.

HAMBURG WHEEL TRACKING TEST

The Hamburg wheel rutting test is a test method for determining the moisture susceptibility and rutting potential of compacted asphalt paving mixtures. Texas DOT test method Tex -242-F was used to perform the Hamburg wheel rutting test.

Test samples were made to the JMF at the optimum AC from the mix design previously described. A total of six sets of sample were prepared. Each set contained two samples. Two sets of control samples were made with and without Anti-strip. The other four sets were WMA samples containing WMA additives Aspha-min and Sasobit each with and without Anti-strip, respectively. For WMA samples with Aspha-min, mixing method (a) was used. The compaction temperature for all WMA samples was 300˚ F. The samples were compacted in SGC to the specified height of 75 mm and 150 mm diameter at 7 %(±0.5) air voids.

Hamburg wheel track test specimens were mounted in the test molds using Plaster- of – Paris with a ratio of 1:1 plaster to water. The plaster was poured to the height of the specimen. The plaster was allowed to set for 45 minutes. Hot water was added to the wheel tracking device to a depth of one inch above the top surface of the specimen. Two water heaters were used to maintain the test temperature at 50 (±1) ˚C. When the water reached the test temperature, 50 (±1) ˚C for 30 minutes, wheels were lowered onto the specimens and the LVDT readings were adjusted before starting the test. The specimens were loaded until either the maximum rut depth value was reached, ½ inch (12 mm), and the number of cycles recorded, or the maximum number of cycle (10,000) was reached. The stripping inflection point was determined from the graph of rut depths vs number of cycles. This defines the number of passes at which moisture damage starts adversely affecting the mixture. The higher the stripping inflection point the less the asphalt mixture is likely to strip or be damaged by moisture.

DYNAMIC MODULUS (E*)

AASTHO TP 62 was performed to determine the dynamic modulus (E*) and phase angle of the asphalt mixtures over a range of temperatures and loading frequencies.

Test samples were made to the JMF at the optimum AC from the mix design previously described. A total of six sets of sample were prepared. A set contained two samples. Two sets of control samples were made with and with out Anti-strip. The other four sets of WMA samples contained Aspha-min and Sasobit each with and without an anti-strip, respectively. For WMA samples with Aspha-min, mixing method (a) was used. The compaction temperature for all WMA samples was 300˚ F. The test samples were compacted in the SGC to the specified height of 175 mm by 150 mm diameter at 7 %(±1%) air voids.

The compacted samples were then cored and sawed to 100 mm diameter by 150 mm tall resulting in a sample with 4.5 %(± 1) air voids. AASTHO T 166 and AASTHO T 269 were used to find the bulk specific gravity and percent air voids of the cored and sawed specimens. Six steel studs were fixed to the sides of each specimen with epoxy cement to hold three linear variable displacement transducers (LVDTs). The LVDT had a gauge length of 4 inches. Care was taken to attach the studs 4 inches apart and 2 inches from the center of the sample. Once the epoxy was dried and studs were firmly attached to the samples, they were ready for testing.

Dynamic modulus test specimens were set on the base plate inside the environmental chamber, LVDTs were fixed to the metal studs on the specimen, the actuator was positioned close to top plate and a contact load was applied. The test temperature and LVDTs were adjusted and the sample preconditioned with 200 cycles at 25 Hz.

The specimens were tested at 4.4˚C, 21.1˚C, 37.8˚C and 54.4˚C at loading frequencies of 0.1, 0.5, 1.0, 5, 10 and 25 Hz at each temperature. Testing at a given temperature started with highest frequency of loading and proceeding to the lowest. Four different stress levels were applied for the four different temperatures (150 psi, 75 psi, 37 psi, 8 psi). The dynamic modulus values E * (psi) and the phase angle over a range of temperatures and loading frequencies were recorded from the computer reading.

DENSIFICATION

To determine the maximum reduction in compaction temperatures due to WMA additives, densification testing was performed over a range of test temperatures. Test samples were made to the JMF at the optimum AC from the mix design previously described. Test samples were mixed and compacted using Control and WMA temperatures. After curing the mix samples for 2 hours, compaction was performed using two compactors, a Superpave Gyratory Compactor (SGC) and Asphalt Vibratory Compactor (AVC).

For SGC compaction, a total of four sets of samples were prepared. One Control set and three sets using WMA additives, two with Aspha-min and one with Sasobit. For WMA samples with Aspha-min, samples were prepared using both Aspha-min mixing method (a) and (b) with each set containing two samples, respectively for a total of 8. For Sasobit, a total of 6 samples were prepared with each set containing two samples.

Samples were mixed in a bucket mixer and then cured in an oven for two hours at the compaction temperature before compaction. The cured samples were then compacted in the SGC to 125 gyrations at 300˚F, 250˚ F, 225˚F, 200 ˚F and the height recorded. Percent compaction and air voids of the test specimen over a range of control and WMA temperatures were recorded.

The second compactor used in the test was AVC. The AVC simulates the actual road compaction better than the SGC and is reported to be more sensitive to the change in compaction temperature than the SGC [11]. Compaction in the AVC was performed in accordance with the manufactures recommendation [17]. Test samples were made to the JMF at optimum AC from the mix design previously described. A 150 mm diameter cylindrical mold was used for AVC compaction. A system pressure (compaction pressure) of 90 psi and counter balance pressure of 30 psi was used. The compaction time was 25 seconds. Several trials were performed to determine the mass of the mix so the mold would not bottom out during compaction.

A total of 3 sets of mix samples were prepared. One set of samples at Control and the other two using WMA additives, Aspha-min and Sasobit, respectively. Each set contained three samples. For Aspha-min, mixing method (b) was used. A total of 9 samples were made with each WMA additives. Control samples were compacted at 300˚F and WMA samples were compacted at 300 ˚F, 250˚F and 200˚F. AASTHO T166 and T 269 were used to find the Gmb and percent air void of the compacted samples.

CHAPTER IV

TEST RESULTS AND DISCUSSIONS

MOISTURE SENSITIVITY TEST

ASTM D 4867 was performed to determine the moisture sensitivity of the samples. The test results and graphical plot of the results are shown in Table 7 and Figure 4, respectively. The results show the average tensile strength of dry and conditioned specimens and average tensile strength ratio (TSR) of the WMA and Control samples.

TABLE 7 Moisture Sensitivity Test Results for Control and WMA Mixes

Mix Type	Dry Strength, (psi)	Conditioned Strength, (psi)	TSR %
Control	124.12	70.17	0.56
WMA with Aspha-min	131.61	62.73	0.48
WMA with Sasobit	106.41	78.13	0.73
Control with ANS	98.38	87.49	0.89
WMA with Aspha-min & ANS	96.72	74.55	0.77
WMA with Sasobit & ANS	67.71	56.22	0.83

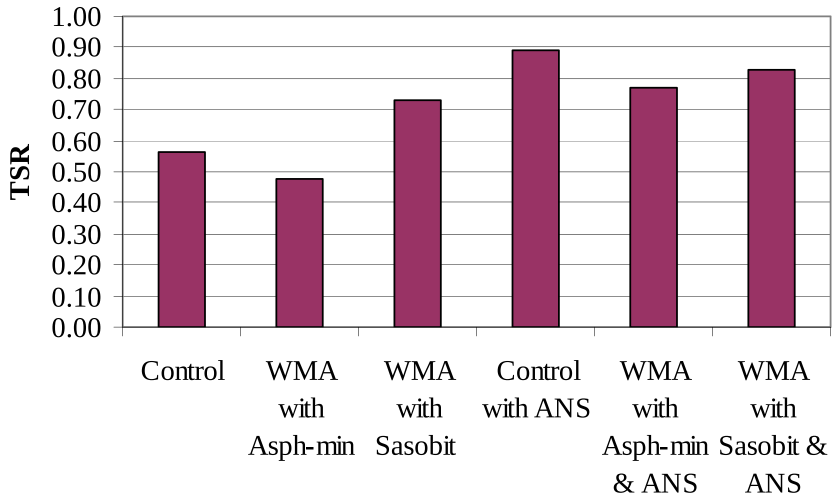

Figure 4 TSR of WMA & Control Mixes

The test results showed that none of the mixes (control and WMA) passed the ODOT recommended minimum TSR value of 0.8 without anti-stripping agent. Sasobit had the highest conditioned strength and highest TSR values of the WMA additives evaluated.

To increase the moisture resistive potential of the mixes, liquid anti-strip agent was added. Addition of liquid anti-stripping agent to the control and WMA mixes substantially increased the TSR value. For Control and Aspha-min mixes, the addition of liquid anti-stripping agent decreased the dry strength and increased the conditioned strength resulting in a higher TSR. For the Sasobit mix, the liquid anti-stripping agent decreased both strengths, more pronouncedly the dry strength than conditioned, to increase the TSR.

Based on the test results, the granite aggregate would require liquid anti- stripping agent to meet the ODOT specifications. The WMA additives lowered the TSR of the mixes, Sasobit was found to be more resistive to moisture induced damage than Aspha-min. The reason behind the lower TSR value of Aspha-min mix is probably due to residual moisture left from the foaming process of Aspha-min.

HAMBURG WHEEL TRACKING TEST

The Hamburg wheel rut test was performed in accordance with Texas DOT test method Tex-242-F. The test was conducted to evaluate the moisture damage and rutting potential of control and WMA mixtures.

Figures 5 through 10 shows the results of rut depth with load cycle for the Control, Ashpa-min and Sasobit mixes, with and with out ANS, respectively. The inflection point, which has been associated with stripping, is indicated on each plot. Figures showed Sasobit samples did not have well defined stripping inflection point.

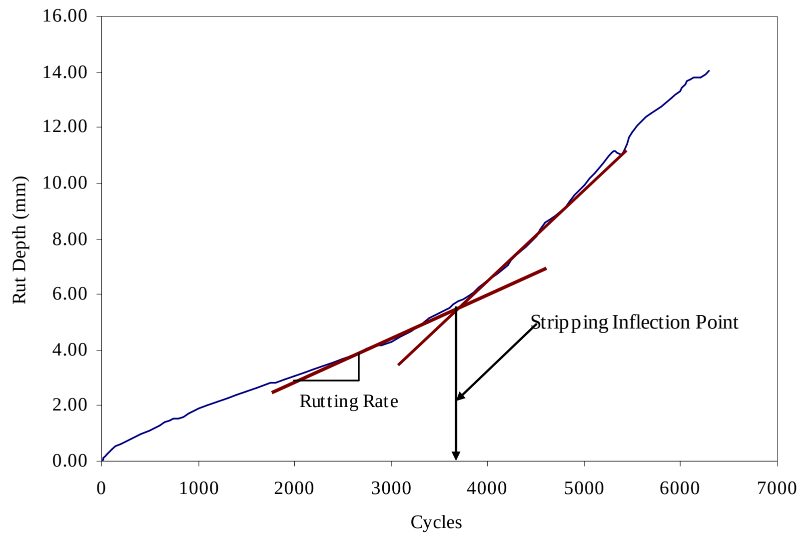

Figure 5 Hamburg Rut depth vs Load cycles for Control mix without ANS

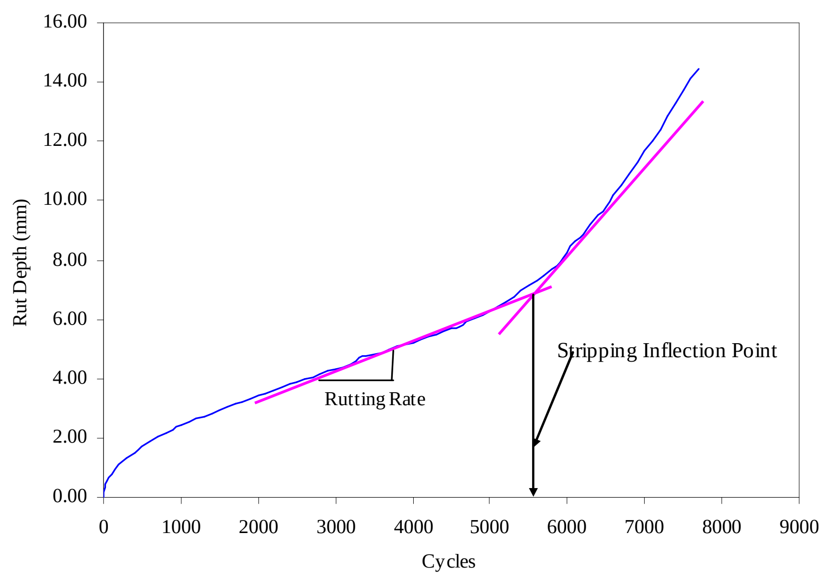

Figure 6 Hamburg Rut depth vs. Load cycles for Control mix with ANS

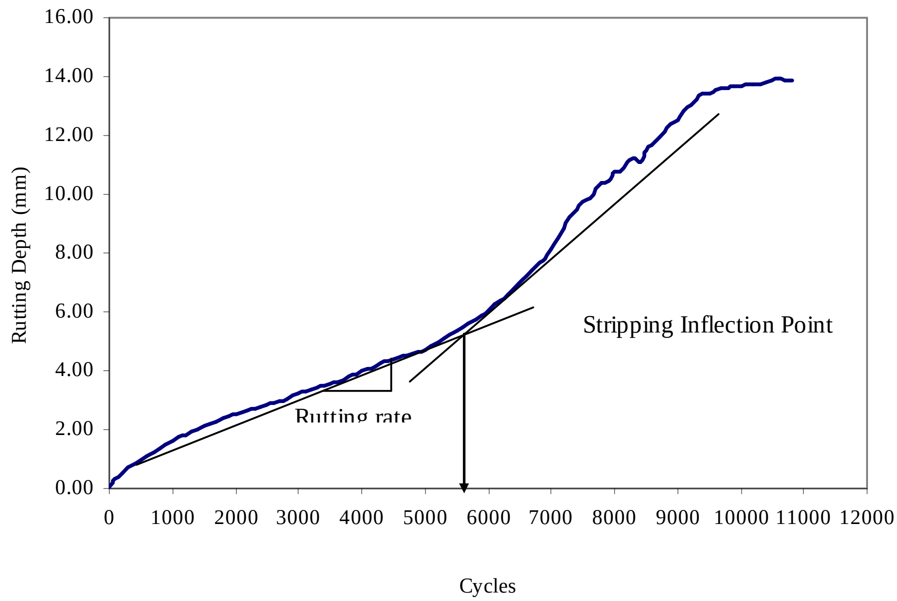

Figure 7 Hamburg Rut depth vs. Load Cycles for Aspha-min without ANS

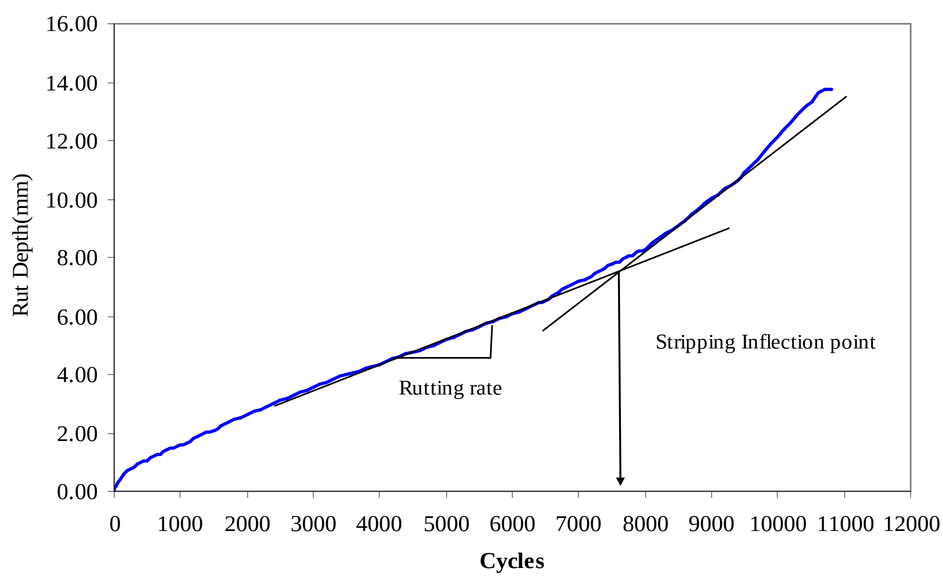

Figure 8 Hamburg Rut depths vs Load cycles for Aspha-min with ANS

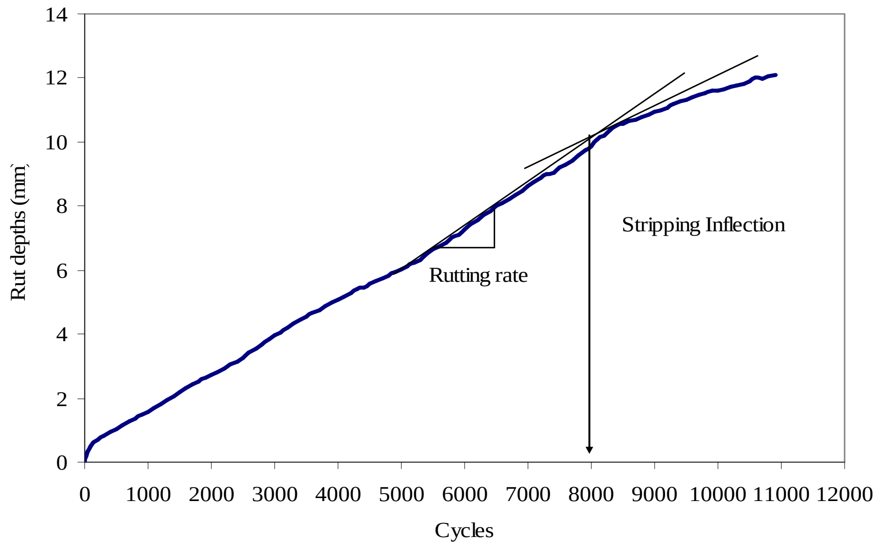

Figure 9 Hamburg Rut depth vs Load cycles for Sasobit without ANS

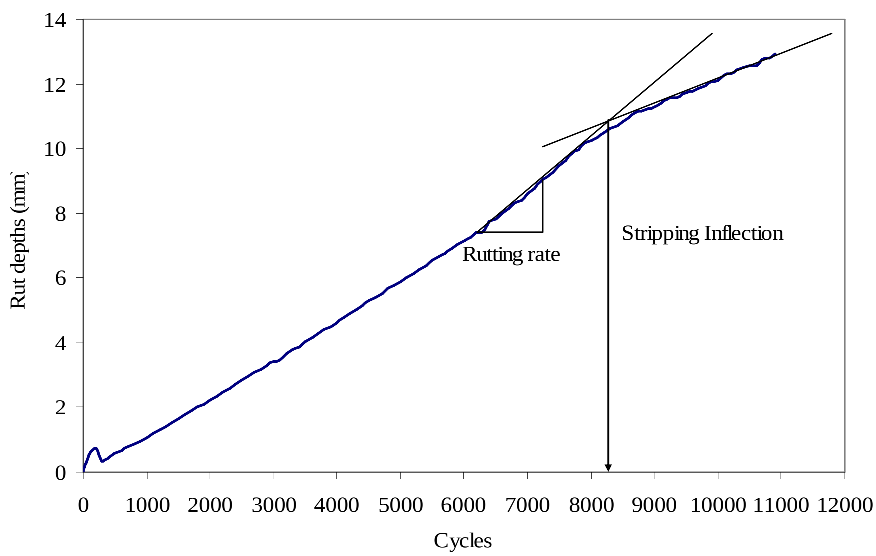

Figure 10 Hamburg Rut depths vs Load cycles for Sasobit with ANS

The number of cycles required reaching a ½" rut depth and the stripping inflection points are shown in Table 8 and the results presented graphically in Figure 11 and 12.

Table 8 Hamburg Test Result for Control and WMA Mixes

Mix	Stripping Inflection Point, cycles	No of cycles for 1/2" Rut depth
Control	3650	5800
WMA Aspha-min	5700	9075
WMA Sasobit	8000	10900
Control with ANS	5650	7280
WMA Aspha-min with ANS	7600	10250
WMA Sasobit with ANS	8400	10400

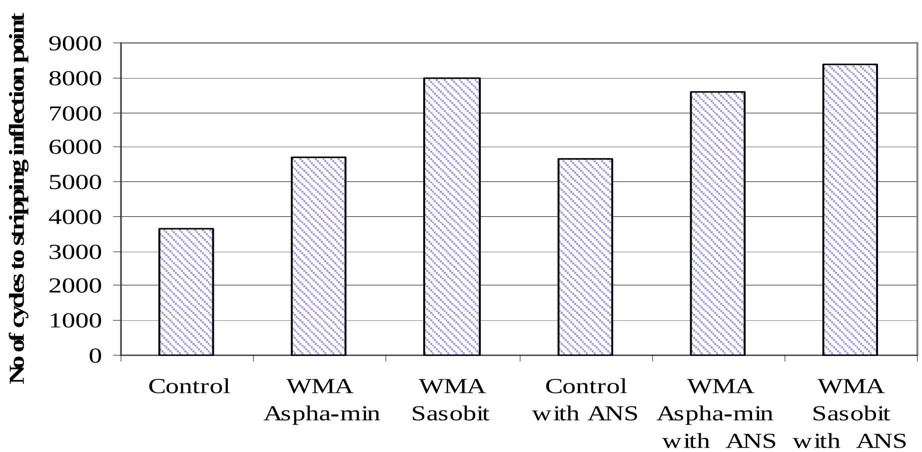

Figure 11 Hamburg for Stripping inflection point

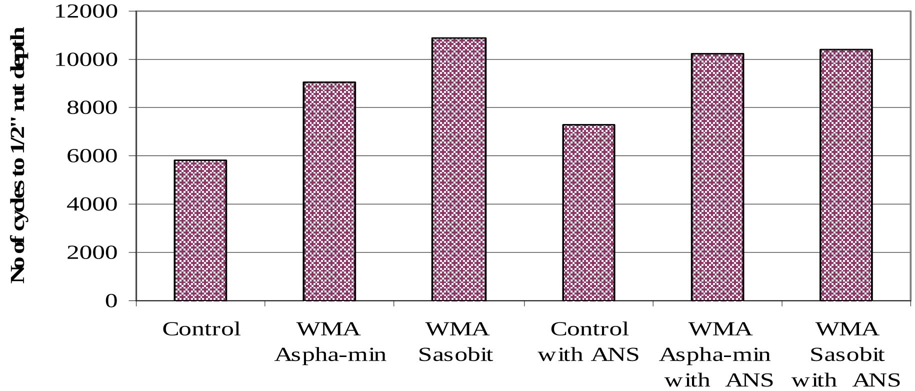

Figure 12 Hamburg for ½" Rut depths

The test results showed both WMA mixes had a higher stripping inflection point than the Control mix. The stripping inflection point defines the number of cycles at which the deformation of the sample is the result of both moisture damage and rutting. Comparing WMA mixes, Sasobit mix had a higher stripping inflection point than Aspha-min. The test results showed that the addition of liquid anti-stripping agent increased the required number of cycles to reach the stripping inflection point for both Control and WMA.

For the rut depth test, the results showed both WMA mixes required a higher number of cycles to reach ½ "rut depth than the Control mix. Comparing WMA mixes, Sasobit required a higher number of cycles to reach ½" rut depth than Aspa-min. The addition of an anti-stripping agent increased the required number of cycles to reach ½" rut depth for the Control and Aspha-min mixes. For Sasobit, mix the addition of liquid anti-stripping agent decreased the required number of cycles for ½" rut depth slightly but it was still higher than both Control and Ashpa-min mixes.

Based on the test results, WMA mixes with and without liquid anti-stripping agent performed better than the control mix. The required number of cycles for stripping inflection point and the ½ “ rut depth of the WMA mixes without liquid anti-stripping agent are higher than the Control mix with liquid anti-stripping agent. This shows that, based on the Hamburg wheel tracking test, the WMA is less prone to stripping and moisture induced rutting than the Control mix.

A summary of the test results from the Hamburg wheel tracking device and corresponding TSR values from moisture sensitivity test are presented in Table 9. The TSR test results indicated poor resistance to moisture induced damage but the addition of anti strip agent improved the resistance of mixes to moisture induced damage. The test results from the Hamburg wheel-tracking device showed slightly different results. As shown in Figures 3, 4, 5, 6 and 7 inflection points were not well defined. The Hamburg results showed WMA stiffened the mix by increasing the number of cycles to ½ “rut depth and increasing inflection point. The addition of anti-stripping agent increased the number of cycles required to reach the stripping inflection point for both WMA and Control mixes. Anti-stripping agent increased the stripping inflection point for Control and Ashpa-min mixes but slight decrease for Sasobit mix. An anti-stripping agent was required to increase the moisture sensitivity (TSR) of both Control and WMA mixes whereas in the Hamburg, the addition of liquid anti- strip agent did not show substantial increase in stripping inflection point and rutting potential

Table 9 Hamburg and Moisture Sensitivity Test Results

Mix Type	Stripping Inflection Point cycles	No of cycles for 1/2" Rut depth	TSR %
Control	3600	5800	0.56
WMA Aspha-min	5700	9100	0.477
WMA Sasobit	7700	10900	0.73
Control with ANS	5600	7300	0.89
WMA Aspha-min with ANS	7600	10300	0.77
WMA Sasobit with ANS	8400	10400	0.83

DYNAMIC MODULUS TEST

AASTHO TP 62-03 was followed to perform the dynamic modulus test. This test was performed to find the difference in dynamic modulus (E*) of WMA and Control mixes. The test results are presented in Table 10. The test results show the average dynamic modulus (E*) of WMA and control mix at four different temperatures with each temperature having six different frequencies. The E* test is performed at different frequencies and test temperature because frequency and test temperature have a significant effect on E*. Figure 12 shows the average E* for each mix at 5 Hz. Similar trends are expected at the other test frequencies.

The test results showed both WMA and Control mixes had the highest dynamic modulus E* values at the lowest temperature 4.4˚C, gradually decreasing towards higher temperatures. Also, dynamic modulus (E*) is maximum at the highest frequency and gradually decrease toward the lower frequency.

Table 10 Dynamic Modulus (E*) of WMA and Control Mixes

Test (Temp)˚C	Frequency	Control	WMA Asph-min	WMA Sasobit	Control & ANS	WMA Asph-min & ANS	WMA Sasobit& ANS
					E* (psi)		
4.4	25	4,645,969	6,670,820	4,910,595	3,322,871	3,584,911	3,453,301
	10	3,573,471	5,038,806	4,348,870	2,781,852	3,127,971	2,954,589
	5	2,949,995	3,367,379	3,692,955	2,421,600	2,748,252	2,599,484
	1	1,999,051	2,458,555	2,630,588	1,750,347	1,995,179	1,875,638
	0.5	1,679,607	1,837,703	2,297,347	1,529,980	1,736,649	1,621,030
	0.1	1,088,190	1,283,875	1,577,005	1,088,953	1,214,958	1,135,216
21.1	25	1,621,498	1,752,580	2,137,601	1,388,436	1,862,024	2,003,538
	10	1,140,297	1,323,112	1,673,716	1,040,512	1,204,196	1,383,516
	5	895,801	1,050,045	1,361,417	824,535	920,485	1,078,168
	1	522,236	608,523	857,327	478,883	520,815	630,564
	0.5	404,964	469,180	668,885	372,509	401,116	477,622
	0.1	227,037	261,958	390,893	212,261	226,141	269,759
37.8	25	408,078	514,975	740,599	384,896	373,963	675,356
	10	276,856	361,619	617,782	259,942	251,657	523,936
	5	203,477	260,618	446,753	191,782	189,749	378,934
	1	110,349	135,850	275,872	104,147	102,478	185,061
	0.5	87,040	103,494	164,659	83,320	82,269	144,371
	0.1	70,162	65,808	111,783	60,786	55,888	91,402
54.4	25	131,459	181,439	227,350	129,139	129,099	241,390
	10	97,992	134,630	156,461	98,502	95,745	165,212
	5	74,958	103,641	117,731	80,272	78,906	119,638
	1	51,468	62,285	70,348	50,430	52,784	70,727
	0.5	46,421	56,099	58,832	44,679	47,471	58,740
	0.1	41,103	50,820	44,787	36,460	43,519	45,405

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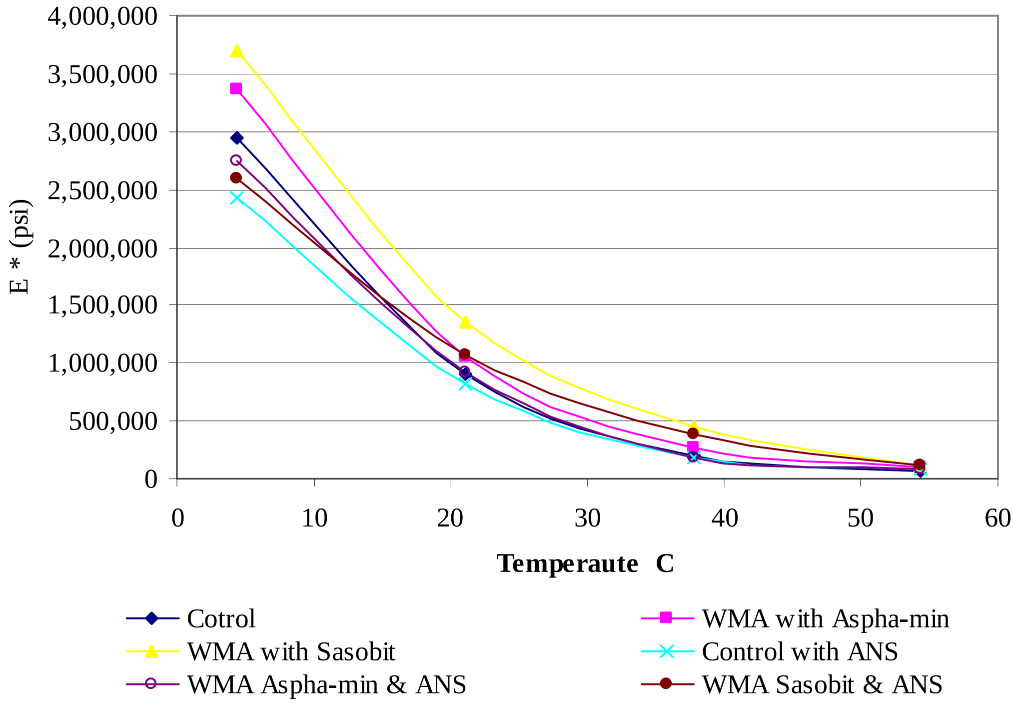

Figure 13 Dynamic Modulus (E*) Vs Test Temperature at 5 Hz

Analysis of variance (ANOVA) was performed to determine if the WMA additvies had a significant effect on E*. The analysis was performed at a constant frequency of 5 Hz and at temperatures of 4.4˚C, 21.1˚C, 37.8˚C, 54.4˚C. Dynamic modulus (E*) test results were taken as dependent variables and WMA additives and anti-stripping agent were taken as independent variables.

The test results from the ANOVA at 4.4˚C (Table 11), showed that null hypothesis was true, or the mean values of (E*) were not significantly different (alpha=0.05). The addition of WMA additives, anti-stripping agent and their interaction did not significantly affect the dynamic modulus at 4.4˚C.

Table 11 ANOVA for (E*) at 4.4˚

Source	Degrees of Freedom	Sum Squares	Mean Square	F Ratio	Prob.> F
Additives	2	477601247756	238800623878	0.41	0.6832
ANS	1	1.6740E12	1.6740E12	2.85	0.1425
Additives*ANS	2	184181676108	92090838054	0.16	0.8584
Error	6	3.5276E12	587942434391		
Total	11	5.8634E12			

As shown in Table 12, at 21.1˚C the ANOVA showed the null hypothesis was not true, or the mean values of (E*) were statistically different at a significance level of 0.05. Based on the results, both WMA additives and anti-stripping agent had significant effects on dynamic modulus. The interaction between the additives and anti-stripping agent showed no significant effect on dynamic modulus. Duncan's Multiple Range Test for (E*) was further performed to determine which additives were statistically different. The results at 21.1˚ C are shown in Table 13. Means with same letter are not significantly different at a confidence limit of 95%. The results showed that mean (E*) of Sasobit mix was larger and statistically different from Aspha-min and the Control mix. The mean (E*) values of Aspha-min and the Control were not significantly different. Table 13 also shows Duncan's Multiple Range Test on E* for the mix with and without liquid anti-strip at

21.1˚ C. Based on the results the addition of an anti-stripping agent significantly reduced the dynamic modulus.

Table 12 ANNOVA for (E*) at 21.1˚C

Source	Degrees of Freedom	Sum Squares	Mean Square	F Ratio	Prob.> F
Additives	2	266642595073	133321297537	11.6	0.0087
ANS	1	78109212492	78109212492	6.8	0.0403
Additives*ANS	2	23985007056	11992503528	1.04	0.4084
Error	6	68958433391	11493072232		
Total	11	437695248013			

Table 13 Duncan's Multiple Range Test for E* at 21.1˚

Grouping*	Mean (E*)	N	Mix Type
A	1219792	4	WMA Sasobit
B	985265	4	WMA Aspha-min
B	860168	4	Control
A	1102421	6	without ANS
B	941063	6	with ANS

* Mean with the same letter not significantly different

The ANOVA at 37.8˚C is shown in Table 14, the test results showed that the null hypothesis was not true, the mean values of E* were statistically different at a significance level of 0.05. Based on the results, WMA additives had significant effect on dynamic modulus. The anti-stripping agent and the interaction between additives and anti-stripping agent showed no significant effect on dynamic modulus.

Table 14 ANNOVA for (E*) at 37.8˚C

Source	Degrees of Freedom	Sum Squares	Mean Square	F Ratio	Prob.> F
Additives	2	82134513130	41067256565	35.7	0.0005
ANS	1	3024124000	3024124000	2.63	0.1561
Additives*ANS	2	2295974401	1147987201	1.00	0.4225
Error	6	6902201148	1150366858		
Total	11	94356812679			

Duncan's Multiple Range Test for E* was performed to compare the individual mean variation of E* due to addition of WMA additives at 37.8˚C. Table 15 shows the results. Means with same letter not significantly different at confidence limit of 95 %. The results showed that mean E* of Sasobit was larger and significantly different from Aspha-min and the Control mix. Both Aspha-min and Control mixes were not significantly different.

Table 15 Duncan's Multiple Range Test for (E*) at 37.8 ˚C

Grouping*	Mean (E*)	N	Mix Type
A	385277	4	WMA Sasobit
B	225184	4	WMA Aspha-min
B	197629	4	Control

* Mean with the same letter not significantly different

The ANOVA at 54.4˚C is shown in Table 16, the results showed that the null hypothesis was not true, the mean values of E* were statistically different at a significance level of 0.05. Based on the results, WMA additives had a significant effect on dynamic modulus. An anti -stripping agent and the interaction between additives and anti-stripping agent showed no significant effect on dynamic modulus.

Table 16 ANOVA for (E*) at 54.4˚C

Source	Degrees of Freedom	Sum Squares	Mean Square	F Ratio	Prob.> F
Additives	2	3499440343	1749720172	13.76	0.0057
ANS	1	102240894	102240894	0.8	0.4045
Additives*ANS	2	541459890	270729945	2.13	0.2002
Error	6	541459890	270729945		
Total	11	4906329257			

Duncan's Multiple Range Test for E* was performed to compared the individual mean variation of E* due to addition of WMA additives. Table 17 shows the results. The test results showed that the mean E* of Sasobit was larger and significantly different from Aspha-min and Control. Both Control and Aspha-min were not significantly different.

Table 17 Duncan's Multiple Range Test for (E*) at 54.4 ˚C

Grouping*	Mean (E*)	N	Mix Type
A	118684	4	WMA Sasobit
B	91274	4	WMA Aspha-min
B	77615	4	Control

* Mean with the same letter not significantly different

Based on the statistical analysis, Sasaobit showed statistically higher (E*) values than both the Aspha-min and Control mix at 21.1˚C, 37.8˚C**,** 54 ˚C. This is probably due to binder stiffening action of Sasobit making the mix stiffer.

DENSIFICATION

Two methods were used to perform the densification test of control and WMA mixes, Superpave Gyratory Compaction (SGC) and Asphalt Vibratory Compaction (AVC). The test was performed to evaluate the compactability of mixes at lower temperatures.

Superpave Gyratory Compaction

For the mixes compacted in the SGC, the test results are shown in Table 18 and results presented graphically Figure 14. The test results show the average bulk specific gravity (Gmb) and percent air voids (VTM) of the control and WMA mixes compacted at different temperatures. All the mixes were compacted to 100 gyrations.

Table 18 SGC Test Results for WMA and Control Mixes

	Compaction Temperature (F)	Bulk Specific Gravity (Gmb)	Void in Total Mix % (VTM)
Control	300	2.286	4.3
WMA Aspha-min Method (a)	300	2.301	3.8
	250	2.305	3.7
	225	2.303	3.8
	200	2.304	3.6
WMA Aspha-min Method (b)	300	2.303	3.7
	250	2.311	3.4
	225	2.305	3.5
	200	2.304	3.7
WMA Sasobit	300	2.319	3.1
	250	2.343	2.55
	200	2.388	2.7

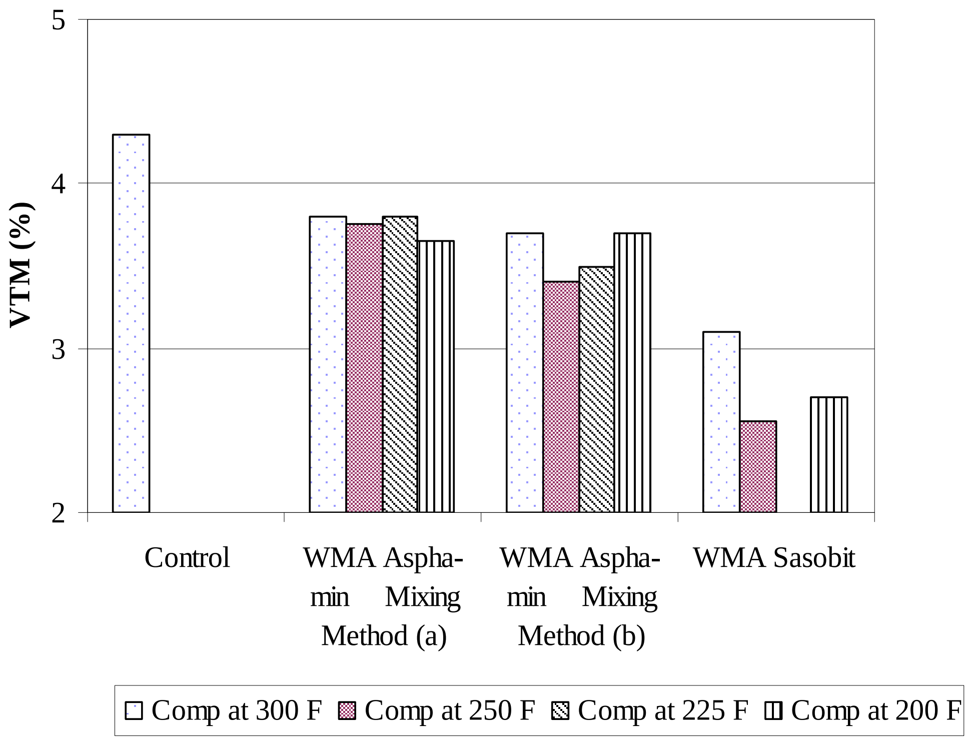

Figure 14 Densification Results over Range of Temperature for SGC

At 300˚F, the test results showed that WMA mixes had reduced air void levels compared to the Control mix. This indicates better compactibiliy of WMA mixes than conventional HMA mixes. However, there were only slight changes in air void contents for WMA mixes with a change in compaction temperature.

For the Aspha-min mix for using method (a) and (b) an ANOVA was performed to find any significant difference using two methods over the range of compaction temperatures. Table 19 shows the ANOVA results. The test results showed that the null hypothesis was true, the means value of VTM using the two different mixing methods (a) and (b) over a range of temperatures were not statistically different at a significance level of 0.05.

However, there was a significant difference at a level of significance of 0.06 with method (b) compacting denser than method (a). The interaction had no significanct effect.

Table 19 ANOVA for Aspha-min Method (a) and (b)

Source	Degrees of Freedom	Sum Squares	Mean Square	F Ratio	Prob.> F
Method	1	0.0756	0.756	4.84	0.059
Temp	3	0.0818	0.0273	1.75	0.234
Method* temp	3	0.1218	0.0406	2.6	0.1245
Error	8	0.1250	0.0156		
Total	15	0.4043			

An (ANOVA) was run to analyze the densification data of the SGC with VTM as response variable and the Control and WMA mixes as variable factors. The results are shown in Table 20. The results showed that the null hypothesis was not true, the mean values of VTM were statistically different at a significant level 0.05. To find the factors which were significantly different from their mean value of VTM, Duncan’s Multiple Range test was performed. Table 21 shows the results from Duncan’s Multiple Range test on mix type and temperature. Means with the same letter not significantly different at confidence limit of 95%.The test results showed that the Control mix at 300 ˚F was significantly different from all WMA mixes. For Aspha-min, mix using method (b) at 250˚F was statically different than Aspha-min mix at other compaction temperatures. For Sasobit, mix compacted at 300˚ F was statically different than mix compacted at 200˚ F and 250˚ F. The test result obtained from the Duncan's Multiple Range Test validated that SGC is less sensitive to the change in compaction temperature for the WMA mix. This confirms what NCAT found [11, 12]

Table 20 ANOVA for SGC Densification

Source	Degrees of Freedom	Sum Squares	Mean Square	F Ratio	Prob.> F
Mix	11	5.65125	0.51375000	22.42	0.0001
Error	12	0.275	0.0223		
Total	23	5.926			

Table 21 Duncan's Multiple Range Test for VTM

Grouping*	Mean VTM	N	Mix Type and Temperature
A	4.35	2	Control (300˚F)
B	3.8	2	Aspha-min method (a) at (300˚F, 250˚F, 225˚F, 200˚F), method (b) at (300˚F, 225˚F, 200˚F)
C& B	3.75, 3.65, 3.55	2	Aspha-min method (a) at (250˚F, 200˚F) & method (b) at(300˚F, 225˚F, 200˚F)
D	3.4, 3.1	2	Aspha-min method (b) at (250˚F) & Sasobit at (300˚F)
E	2.7,2.5	2	Sasobit at (200˚F, 250˚F)

* Means with the same letter are not significantly different

Asphalt Vibratory Compaction

The AVC has been shown to be more sensitive to compaction temperature than SGC [11, 12]. Therefore, the mixes were compacted in the AVC over same range of temperatures. The test results are shown in Table 22 and presented graphically in Figure 15. The test results show the mean average bulk specific gravity and air voids (VTM) of the mixes compacted over range of the temperature.

Table 22 AVC Test Result for WMA and Control Mixes

	Compaction Temperature (F)	Bulk Specific Gravity (Gmb)	Void in Total Mix % (VTM)
Control	300	2.262	6.8
WMA Aspha-min Method (b)	300	2.296	5.6
	250	2.281	6.1
	200	2.243	7.67
WMA Sasobit	300	2.262	4.8
	250	2.273	6.4
	200	2.252	7.4

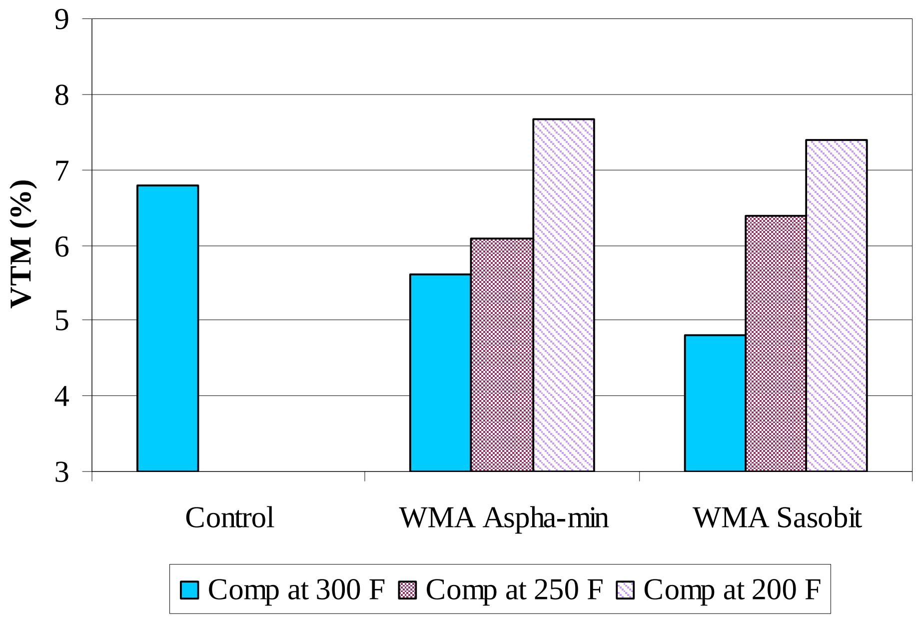

Figure 15 Densification Result over Range of Temperature for AVC

As shown in Figure 14 WMA additives improved the compatibility of the mix at lower temperatures. It appears that compaction temperatures at least as low as 230˚F would result in similar VTM to a conventional HMA mix compacted at 300˚F.

An ANOVA was done to analyze the compactability of mixes in the AVC with VTM as response variable and the Control and WMA mixes as variable factors. The results are shown in Table 23. The test result showed that the null hypothesis was true, the mean values of VTM were not statistically different at significant level 0.05. This showed that the Control and WMA mixes are not statistically different or the WMA additives and compaction temperatures had no significant effect to the densification of mixes in the AVC. It was due to the non repeatability of test results obtained from AVC. The in-cell variability of the test results was large. There was also a problem in maintaining specified air pressure during each test and ODOT has reported difficulty in getting repeatable results in the AVC.

Table 23 ANOVA for AVC Densification

Source	Degrees Freedom	Sum Squares	Mean Square	F Ratio	Prob.> F
Mix	6	10.4432	1.7405	1.53	0.2622
Error	10	11.3520	1.1352		
Total	13	21.7952			

CHAPTER V

CONCLUSION

The Following conclusions are made based on the results from the laboratory testing Aspha-min and Sasobit.

- The moisture sensitivity test, ASTM D 4867, showed both WMA additives were susceptible to moisture damage as indicated by TSR value lower than the ODOT recommended minimum of 0.8. Sasobit mix showed higher TSR values than either the Aspha-min or Control mixes. However, the addition of 0.5% liquid anti-stripping agent by mass of asphalt cement improved the TSR values of all mixes. Sasobit and Control passed mixes exceeded the ODOT minimum TSR value of 0.8 with 0.5% Anti-strip whereas Ashpa-min did not pass.

- The Hamburg wheel tracking test results showed better resistance to moisture induced rutting for WMA mixes than Control mixes. Without addition of liquid anti-stripping agent both Sasobit and Aspha-min required a higher number of cycles to reach the stripping inflection point and ½" rut depth than the Control mix. Sasobit had a higher inflection point and cycles to ½" rut depth than Aspha-min.

The increase in moisture induced rutting resistance of the WMA mixes might be due to the higher stiffness of WMA mixes at 50˚C or the lesser moisture induced rutting potential of the WMA than Control mixes. The addition of 0.5% of liquid anti-stripping agent by mass of asphalt cement, the WMA mixes improved the moisture induced rutting resistance slightly but not as significantly compare to the TSR test.

- Dynamic modulus (E*) testing showed mixed results. The statistical analysis showed no significant effect of WMA additives on the stiffness of the mix compared to the Control mix at 4.4˚C, but at the higher test temperatures, the results showed a significant effect. The WMA mixes were stiffer than the Control mixes. This increased stiffness might be the reason that the WMA mixes showed higher moisture induced rutting resistance in the Hamburg wheel tracking test than the Control mix. The addition of 0.5% of liquid anti-stripping agent by mass of asphalt cement had no significant effect on mix stiffness except at 21.1˚C. At 21.1˚C, the test results showed that the addition of liquid anti-stripping agent reduced the stiffness of mix.

- The densification test using the SGC indicated that the WMA mixes showed better compactibility at lower test temperatures compared to the Control mixes. The test results showed that the addition of WMA additives significantly reduced the air void level compare to the Control mix compacted at 300˚ F. However, statistical analysis showed no significant change in compactibility of WMA mixes at lower compaction temperatures. For Aspha-min, the statistical analysis showed that there was no significant difference in compactibility of mix using mixing method (a) or (b). However, at a significance level of 0.06, method (b) had better compactibility than method (a).

- The AVC test results showed that WMA additives mixes improved the compactibility of the mixes compare to the Control mixes compacted at 300˚F. The WMA mixes reduced the compaction temperature by 70˚F. However, the statistical analysis showed no significant difference in compactibility of the WMA and Control mixes. The statistical analysis also showed that the WMA mixes were non sensitive to compaction temperatures. This might be due to the repeatability, uncertainties and large in-cell variability using the AVC test.

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VITA

SUSHANTA BHUSAL

Candidate for the Degree of

Master of Science/Civil Engineering

Thesis: A LABORATORY STUDY OF WARM MIX ASPHALT FOR MOISUTRE DAMAGE POTENTIAL AND PERFORMANCES ISSUES

Major Field: Civil Engineering

Biographical:

Personal Data: Sushanta Bhusal

Education: Bachelor in Civil Engineering, Institute of Engineering, Pulchowk , Lalitpur, Nepal

Completed the requirements for the Master of Science in Civil Engineering at Oklahoma State University, Stillwater, Oklahoma in December, 2008.

Experience: Graduate Research Assistant, School of Civil and Enviromental Engineering, Oklahoma State University, Stillwater Oklahoma, January 2007 to October 2008.

Professional Memberships: Member of Nepal Engineering Council.

Name: Sushanta Bhusal Date of Degree: December, 2008

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: A LABORATORY STUDY OF WARM MIX ASPHALT FOR MOISUTRE DAMAGE POTENTIAL AND PERFORMANCES ISSUES

Pages in Study: 52 Candidate for the Degree of Master of Science

Major Field: Civil Engineering

Scope and Method of Study:
A laboratory study was performed to: (a) evaluate the moisture damage potential of WMA (warm mix asphalt); (b) evaluate the dynamic modulus of WMA; and (c) evaluate the effect of mix temperature on densification of WMA. Two WMA additives, Asphamin and Sasobit, and an anti-stripping agent were used for the study. A PG 64-22 asphalt binder and granite aggregate were used to make the WMA and control mixes. The test results were analyzed and the performance of WMA was evaluated and compared to conventional HMA.

Findings and Conclusions:
The moisture sensitivity test results showed that both the WMA and Control mixes showed had low TSR values. However, the addition of 0.5% liquid anti-stripping agent by mass of asphalt cement increased the moisture sensitivity performance by increasing the TSR value of WMA and Control. Hamburg wheel rutting test results showed that the WMA mixes had better resistance to moisture induced rutting than the Control mix. The WMA mixes required a higher number of cycles to reach the stripping inflection point and ½" rut depth. The addition of 0.5% liquid anti-stripping agent by mass of asphalt cement improved the performance but not as significantly as in the TSR test. The dynamic modulus E* test results showed that WMA additives significantly increased the stiffness of the mixes at higher test temperatures. The test results showed that the addition of 0.5% liquid anti-stripping agent by mass of asphalt cement did not significantly affect the stiffness of mixes expect at 21.1˚C. The densification test results using SGC (Superpave gyratory compactor) and AVC (Asphalt vibratory compactor) showed that WMA additives improved the compactibility of the mixes. The AVC test results showed that WMA reduced the compaction temperature by 70˚F. However, for the WMA mixes compacted over a range of temperatures, both SGC and AVC test results showed no significant difference in compactibility.

ADVISOR'S APPROVAL: Dr. Stephen A. Cross